UCRL-JC-151409

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

Building a World-Class Safety Culture: The National Ignition Facility and the Control of Human and Organizational Error

C. T. Bennett, G. Stalnaker

December 06, 2002

ASSE- American Society for Safety Engineers,
Atlanta, GA, March 13, 2003

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

BUIDLING A WORLD-CLASS SAFETY CULTURE: THE NATIONAL IGNITION FACILITY AND THE CONTROL OF HUMAN AND ORGANIZATIONAL ERROR.

C. Thomas Bennett, L-438, Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550-92341, 925.423.2366; George F. Stalnaker, DuPont Safety Resources, 121 Continental Drive, Suite 207, Newark, DE 19713, 302.363.7860.

INTRODUCTION

Accidents in complex systems send us signals. They may be harbingers of a catastrophe. Some even argue that a "normal" consequence of operations in a complex organization may not only be the goods it produces, but also accidents and—inevitably—catastrophes.[1]

We would like to tell you the story of a large, complex organization, whose history questions the argument "that accidents just happen." Starting from a less than enviable safety record, the National Ignition Facility (NIF) has accumulated over 2.5 million safe hours.[2] The story of NIF is still unfolding. The facility is still being constructed and commissioned. But the steps NIF has taken in achieving its safety record provide a principled blueprint that may be of value to others. Describing that principled blueprint is the purpose of this paper.

The first part of this paper is a case study of NIF and its effort to achieve a world-class safety record. This case study will include a description of (1) NIF's complex systems, (2) NIF's early safety history, (3) factors that may have initiated its safety culture change, and (4) the evolution of its safety blueprint. In the last part of the paper, we will compare NIF's safety culture to what safety industry experts, psychologists, and sociologists say about how to shape a culture and control organizational error.

A CASE STUDY: CREATING A WORLD-CLASS SAFETY CULTURE AT THE NATIONAL IGNITION FACILITY

WHAT IS THE NATIONAL IGNITION FACILITY?

Purpose of NIF

NIF will use the world's largest laser to compress and heat BB-sized capsules of fusion fuel to thermonuclear ignition. NIF experiments will produce temperatures and densities like those in the Sun or in an exploding nuclear weapon. The experiments will help scientists sustain confidence in the nuclear weapon stockpile without nuclear tests as a unique element of the National Nuclear Security Administration's Stockpile Stewardship Program. NIF will produce additional benefits in basic science and fusion energy.

The Buildings and the Laser System

NIF is 704 feet long, 403 feet wide, and 85 feet tall—about the size of a football stadium. The $260 million, 7-acre NIF building complex was completed on schedule and within its allocated budget on September 30, 2001. There are 400,000 square feet of structural surfaces, 73,000 cubic yards of poured concrete, 12,700 tons of steel and rebar erected, and 210,000 cubic yards of earth moved.

The 192 laser beams will generate a peak power of 500 trillion watts, 1000 times the electric generating power of the United States. In the master oscillator room, the initial 1 billionth of a joule light pulse is amplified 10,000 times, then split into 48 separate laser pulses. In the preamplifier module, each of the 48 pulses is further amplified 20 billion times, and then split 4 ways to create 192 beams. The beams will focus on a BB-sized piece of material resulting in fusion.

Current Operational Status

Prior to 2000, most of the work conducted on the NIF site was standard large-building construction. During the last year, major construction activities have given way to installation and acceptance testing. Presently a subset of laser beams is undergoing qualification testing and commissioning. The operations in the building range from construction-like activities to experiments in clean room areas similar to those in semiconductor fabrication.

THE CONDITIONS AT NIF PRIOR TO ITS CULTURE CHANGE

Safety Programs in Place Prior to the Change

NIF's on-site contractor had a Laboratory-approved safety program and also its own safety professionals. As the owner, NIF had in place an overarching safety plan and program that covered everyone working on the site. The Laboratory had assigned a safety team dedicated to NIF.

Summary of the Safety Record

Prior to calendar year 2000, our safety record was marred by a Total Recordable Rate (TRR) over fourteen. By comparison, the national average is near five or six. In calendar year 2000, the rate began to drop and was just under 5.0. By the end of calendar year 2001, the TRR was 1.68, where it remained during 2002. In terms of Lost Work Cases (LWC), NIF was averaging over 16 in the years prior to 2000. By 2001, the LWC rate dropped to zero, where it has remained as of this writing (December, 2002). That record represents about 2.5 million safe hours—hours without an LWC. This is a remarkable record given that NIF has heavy construction going on side-by-side with precision optical installation and alignment. The work culture ranges daily from one that might mostly contain laborers to skilled tradesmen to laboratory technicians to engineers and physicists.

WHAT MAY HAVE INITIATED THE CHANGE?

NIF Management Prior to the Change

During the late 1990s, NIF's management staff tolerated our accident rate. We mean by that while NIF's accident rate remained high and unchanging for several years, NIF made no significant change in its safety program. During this early phase, it assumed a distinctly hands off approach to safety management on the work site. NIF senior management took the position that the contractor was responsible to accomplish the technical goals safely.

New NIF Management

As part of a broad organizational change within NIF, a new cadre of upper-level managers was brought in to deal with technical and budget issues. As those issues began to be resolved, those new upper level managers began to focus not only on technical performance, but also safety performance. NIF management also took a more direct, hands-on approach to managing its contractor. As old contracts were rewritten, NIF was able to hold the contractor more accountable for its safety record.

With an upper management focus on safety, people at all levels of the organization began to be more interested in our injury rate. The high rate started to affect morale. The high rate became not only a moral issue. It became one of pride. And it became an issue with NIF's manager, the Department of Energy. NIF was supposed to be a world-class laser facility and it was not managing its safety well.

The new upper management focus on injuries and safety management was a crucial seed in what was to become a top-down, cultural change process.

<u>Key Mid-Level Managers</u>

Another seed for change came when a separate Laboratory laser program unexpectedly ended; and many of those people began to populate NIF. These people brought with them an operations and safety culture that had the beginnings of a world-class safety organization (though it had not yet achieved that status). Partnering with their contractor, AlliedSignal, that laser program put in place strong operations and safety management programs. Its accident rate dropped fourfold in a year.

The stage was now fully set for a cultural change. (1) There was a new upper-level management focus on both safety and technical performance. (2) Line managers who had prior experience in making a safety culture change were filling key positions. (3) A growing, organization-wide, interest in our injury record and a realization that we had to do better. NIF's new safety culture started to evolve then.

THE EVOLUTION OF NIF'S SAFETY BLUEPRINT

A little over two years ago, a worker received a major injury from which he subsequently recovered. That injury resulted in NIF conducting an internal and a DuPont led independent review of our safety programs. Those reviews led to four major themes that have dominated NIF's safety culture change. These themes include (1) establishing a philosophy that all incidents are preventable, (2) influencing safety performance through broad top-down initiatives; (2) establishing a clear line-management commitment to safety and work excellence, and (3) developing Work Teams committed to working within established safety and work envelopes.

<u>NIF's Safety Philosophy</u>

There were many discussions about what our safety goal should be. Should we set the goal at "zero accidents"? Or should we set the goal of merely having "the best" safety record at the Laboratory—which meant (everyone knew privately) NIF would tolerate some number of accidents per year.

The program leader's decision to have "The Goal is Zero!" as our safety goal was a defining moment in NIF's safety history.

At first, it—"The Goal is Zero!"—was merely a slogan and not a goal. With time, people started to realize we could control our culture and our accidents. It was at that point the slogan entered our culture and became our goal.

Influencing Safety Performance Through Broad Top-Down Initiatives

There were several broad, top-down organizational initiatives (many starting about the same time) that influenced NIF's safety culture. One of these initiatives was a management willingness to learn and change as the result of incidents. In a broad organizational fashion, NIF became more aggressive about changing itself when it needed to improve its safety performance.

A new willingness to learn was reflected in incident analyses that became more efficient and thorough in identifying root causes. For example, when a major accident occurred, an organizational stand down took place, along with a reassessment of how we were doing work. Managers were becoming increasingly aware of their roles in an accident.

A recent example of NIF's aggressive, quick acting response to an incident came after a worker injured a finger when his ring got caught on a truck. A policy was instituted banning rings in the construction areas of the site. It was not an issue of how likely it was that another ring-related injury could occur. We had learned that it could happen. And we wanted to prevent it from happening again.

The broad organizational initiatives were documented in a new site safety program. That program brought to the forefront our "core processes" (which, if violated, would result in a work stoppage or disciplinary action). Key line managers were responsible for identifying these practices and developing the procedures for implementing them. Line managers' involvement in developing the procedures was essential to these managers' later commitment.

As NIF's culture evolved, these "core processes" would come to reflect our safety values.

Establishing a Clear, Line-Management Commitment to Safety and Work Excellence

The new site safety program did not have an immediate impact on our injury rate. One barrier to change was the very people—line managers—who needed to implement the new philosophy, policies, and procedures were not doing so. In hindsight, we had overwhelmed them and workers with a paper-centered safety program. And we needed to change it to a people-centered safety program.

To overcome the apparent complexity—and to give line managers value-added tools—NIF set in place broad education programs explaining both our "core safety processes", as well as how upper-management expected them to be implemented. These programs were intended to transform NIF's paper-centered program into the person-centered program we had hoped it would be. These diverse programs included:

1. A suite of web-based safety-leadership courses was tailored for each person's role in the organization. People did not have to wade through four inches of documents. The courses helped show that NIF thought the information was important.
2. A daylong course was specifically directed at helping line managers, team leaders, and workers learn how to communicate with each other about work and safety controls. Managers and workers learned to better understand what to expect of each other.[3]
3. A tiered, formal management walkabout process focused on work authorization standards and communication. The process has gradually become more common. These walkabouts started to close the loop from senior managers' expectations to team leaders' implementation of policies to workers' maintaining the planned safety envelope.

4. Clear lines of work authorization and control were established. This provided a structure for ensuring that Job Hazards Analyses (JHAs) and other safety reviews were performed. Decision points were established for various work packages. These decision points ensured that both technical and safety goals could be met before proceeding. Expectations were being communicated throughout the management chain.
5. Coupled with these programs were the insights of a DuPont consultant that helped our implementation at key points in the process.

<u>Developing Work Teams Committed to Working within Established Safety Envelopes</u>

To make a top-down change process complete, workers need to engage that process. NIF had put philosophies, policies, and procedures in place. It was training line managers. But when the new safety program came out, workers were a bit reticent. They had seen safety programs come and go. They wanted to know: "Does management really care about our safety? What's in it for me?"

Change begins with leaders communicating goals and standards. An effective communication process is simply about how good leaders create an organization in which people can achieve extraordinary goals.

To ensure that the communication process was effective, the following initiatives were engaged at about the same time (some of these we mentioned earlier):

1. The web-based safety leadership courses that informed workers about NIF's safety goals and procedures. This process helped set the stage for change.
2. Tiered management walkabouts emphasized upper management's commitment to safety and provided a venue for workers and managers to create a dialog.
3. Daily Work Team Meetings are held each day before work begins. Work Teams review the safety and technical goals as outlined in the Safe Plan of Action form and then sign it to indicate they understand what needs to be done that day. These meetings reinforce not only good safety and work practices, but also reinforce the notion that safety management flows down through the work authorization chain.
4. The walkabouts and team meetings are venues for team leaders and line managers to personally affirm NIF's commitment to safety and ensure safety envelopes are maintained.

Because NIF's safety culture evolution was a top-down phenomenon, it took the personal leadership of line managers and Work Team Leaders to demonstrate NIF's commitment to safety.

This personal leadership was accomplished through their presence and words. Using a structured work authorization chain, line managers communicated the safety standards established in our JHAs and other safety documents.

How did these first line supervisors ensure that workers maintained their safety and work envelopes? Just as all leaders have in the past, through positive and negative reinforcement. Importantly, the leaders provided that reinforcement with the backdrop of a clearly defined daily safety and work plans. And to ensure the first line supervisors were fulfilling their responsibilities, mid-level managers monitored the work teams.

Was safety leadership executed perfectly? No. But NIF's safety record reflects a major change in workers' performance—and is a testament to the power of focused, personal leadership at all levels in the chain of command.

During the first year of NIF's culture change, the top-down process began to answer the workers' question about whether management cared. Workers started to believe that management did care. Later on, workers' second question (What's in it for me?) began to be answered—the answer being that if work is done as planned, it will likely be done safely and with a sense of accomplishment.

Work performance is not going to change unless it has been reinforced. Without having conducted any formal surveys into worker attitudes, we can only provide our professional judgment about what reinforced the change in worker performance at NIF. We believe those change factors include:

1. Line managers and Team Leaders communicating clear safety and work expectations—and reinforcing good performance during regular supervision.
2. A personal leadership style that communicated NIF's commitment to safety. Workers returned this commitment with their own commitment to working safely.
3. A gradually improving safety record has instilled a frequently verbalized pride in NIF's successes. The safety and work record that NIF is achieving provides a rewarding sense of professional accomplishment to people.
4. Growing peer pressure and personal pride are maintaining NIF's standards and both are other sources of behavior change. More than one worker has said, "I don't want to be the one who wrecks NIF's safety record!" Workers are becoming committed to NIF's safety goals.

COULD NIF DO BETTER? A LOOK AT THE LITERATURE AND WHAT THE EXPERTS SAY ABOUT HUMAN ERROR AND CULTURE

In this section, we will examine what safety industry experts, psychologists, and sociologists have said about (1) the factors that influence human and organizational error and (2) the relationship of productivity and safety. At the end of each section, we will grade NIF in these areas.

The Factors That Influence Human and Organizational Error

At the beginning of the paper we mentioned that some authors believe that even the simplest of organizational systems are so complex that people cannot anticipate all the interactions—making accidents inevitable.[4] In part, the argument is cogent because they put accidents in the context of organizational systems.[5]

But we would argue that accidents—like production—are controllable. And with the mind-set that accidents are "perfectly" controllable comes extraordinary safety records—records of zero accidents for remarkably long periods of time.

We consider human error simply as an action that has an unintended consequence—and is roughly equivalent to an accident.[6] We agree that in some sense the error is the action that leads to an event or accident.[7] But for conciseness we will continue to use the terms error and accident interchangeably.

Because the scope of accident analyses have widened considerably in recent years, we need to consider another term—organizational error—a type of error that always has existed, but not recognized as such. Such errors occur when the "aggregated activities of an organization's members lead to an unintended consequence."[8] Reason (1997) explains the distinction between human and organizational error in the following way.

> Organizational accidents have multiple causes involving many people operating at different levels of their respective companies. By contrast, individual accidents are ones in which a specific person or group is often both the agent and the victim. The consequences to the people concerned may be great, but their spread is limited. Organizational accidents, on the other hand, can have devastating effects on uninvolved populations, assets and the environment. (pg. 1)

Reason argues that the difference between individual and organizational errors is one of extent and degree.[9] Unfortunately, we believe this definition provides justification for shielding upper-level managers from culpability, even from small accidents.

We believe that a human error/accident is a cultural incident. For us, a culture is an interconnected nexus of human influences. This premise means that people do not work in isolation. They are influenced by "many people, operating at different levels" in their organization. This perspective leads one to conclude that every human error-related accident is an organizational accident[10] that could be prevented.

<u>What Is NIF's Grade on Dealing with Organizational Errors?</u>

Has NIF internalized the concept of an organizational accident? Not completely throughout the organization. But it is getting there. Procedures are in place to quickly conduct incident investigations. Classes are taught that include the notion of organizational error. We mentioned earlier the incident when a worker injured his finger when he caught is ring on a truck. NIF did not respond by saying that it was worker error. It responded as if it had committed an organizational error. NIF reacted by instituting a new safety policy restricting wearing of rings.

<u>The Relationship of a Safety Culture on Productivity</u>

Up to this point, we have talked about human error and accidents in the context of safety. But human error can also express itself in poor quality and reliability.

Using the productivity and accident data from almost 14,000 companies, the American Engineering Council concluded that on the average, the "safe" factory is eleven times more likely to be a "productive" one than an unsafe one is.[11] Many world-class safety companies, like DuPont, preach the dogma that safety and productivity are inextricably linked.[12]

People have recognized that there are special organizations that have become remarkably reliable. They have been called High Reliability Organizations (HROs) and defined as ones that conduct tens of thousands of high-consequence operations, essentially error free.[13] What are they like?

> These organizations differ from those analyzed in most of the literature. They seem to have designed their operations around the idea that their task environments present a continual, active threat to safety. The absence of any surprise over a long period of time creates not a feeling of complacency but anxiety that their error-seeking mechanisms are decaying. (Roberts 1993, p. 27)

HROs have demonstrated that accidents are controllable through a systems approach.[14] HROs (as well as most world-class safety companies) exhibit an extraordinary ability to understand their capacity to achieve their goals. At the slightest hint that their goals are not being achieved, they engage change. They adapt.[15]

They adapt by using the principles that shape a culture and influence personal behavior. Some would say that this shows "organizational wisdom."[16] This is best explained by looking at how an HRO reacts to a problem. Say a seal on a pump breaks because a worker failed to perform routine maintenance. An organization could simply react to the poor maintenance practice by punishing the worker and writing a new procedure. An HRO would try to understand the principle behind the failure. HROs and world-class safety organizations ask, "What was the root cause of the incident?" What were the organizational factors? To create an HRO or world-class safety organization, leaders must deal not only with their technical challenges, but also the forces that influence a culture and organizational error.[17]

What Is NIF's Grade on Dealing with Safety Culture and Productivity?

Has NIF tied reliability to safety? Perhaps—but improvement is still possible. There are mechanisms for tracking incidents. For example, when an incident occurs, whether it results in damaged equipment or a personal injury, the same reporting process is used. NIF has a computerized database in which corrective actions are tracked. NIF has put in place a work authorization and safety analysis process that tightly couples work and safety performance. When an incident occurs, NIF aggressively pursues the root cause and is willing to make organizational changes. NIF's recent technical performance achievements—as well as its safety accomplishments—reinforce the notion of the close relationship of safety and productivity.

SUMMARY: A FINAL FOOTNOTE ON NIF

So where is NIF in its safety history? Is it a world-class safety organization? Is it a High Reliability Organization? Is it a world-class safety organization?

Not yet. NIF has a good safety record for now. But HROs and organizations with world-class safety records tend to be very mature organizations. If a gap analysis were done comparing NIF and an HRO/world-class safety organization, we would see that many of the necessary formal structures are in place, but their implementations are uneven.

Because of its youth, NIF has little history to look back on. An HRO is always looking over its shoulder, afraid that an accident or catastrophe might happen. It is continually at work on shoring up its defenses. Roberts (1993, p. 27) wrote that HROs behave as if "the absence of any surprise over a long period of time creates not a feeling of complacency but anxiety that their error-seeking mechanisms are decaying."

But contrary to those who believe that accidents are a normal outcome in a complex organization, we believe the cultural factors leading to safe performance are controllable. With a 2.5 million safe-hour record, NIF has proven that. To sustain its safety record, NIF still needs to make sure that its error-seeking mechanisms do not decay.

ENDNOTES

[1] Several people make this argument either directly or indirectly (Guastello 1995; Perrow p. 5, 1999; Dumas p. 240, 1999). In his book, Perrow explains, "The odd term *normal accident* is meant to signal that...multiple and unexpected interactions of failures are inevitable." Whether or not line managers give credence to Perrow's conclusion (that accidents are a normal course of doing business) will determine how they structure their organizations, lead their people, and prioritize their resources. Furthermore, the organizational belief that accidents are inevitable will set in motion a culture that insidiously influences how workers conduct themselves and manage their personal work.

[2] Those hours represent over two years without a Lost Work Case (LWC).

[3] Individual, team, and organizational factors form the basis of an organization's culture. If this cultural triad is important to organizational performance, can training optimize it? Guzzo and Dickson (1996) documented the positive performance value of incorporating individual, team, and organizational factors into training regimes (Popper and Lipshitz 1998; Zohar 2002).

Others (Helmreich, Wilhelm, Klinect, and Merritt 2001) have looked more specifically at the value of Crew Resource Management (CRM) on error management. CRM is a training method directed at enhancing how individual, team, and organizational factors improve performance. Helmreich and his associates contend that putting CRM in the framework of error recognition, avoidance, and management will promote awareness of an organization's commitment to safety.

[4] Their argument is buttressed by others (Heinrich 1959; Hoyos and Zimolong 1988), who continue the argument by trying to statistically link accidents and catastrophes.

[5] Perrow only gives us examples of systems. He talks about the inputs and outputs of systems. But to our minds, inputs and outputs alone do not define a system. For us, a system is more than its raw materials, processes, and final products.

Medina (1981) provides a more useful definition. She argues that, at a minimum, a system must have (1) inputs, (2) throughputs, (3) outputs, and—importantly—(4) an "intelligent" controller—one that has a goal, monitors error in the system, and corrects the errors. To Medina—and to us—a car without a driver is not a system. For example, an air carrier has its own air traffic control system because the system has goals, which the air carrier attempts to optimize in an intelligent—if not cooperative—fashion. On the other hand, the Federal Aviation Administration's National Air Space does not. To use an overworked analogy, the FAA simply tries to "herd" the air carriers. For an organization to be a system, it must not only have goals (safety and efficiency), but an intelligent controller, a CEO who has a vision of having zero accidents and high reliability.

Will an intelligent controller inevitably make mistakes and have accidents? This is where we begin to diverge with Perrow, who would argue that accidents and catastrophes are a *sine qua non* of a complex organization. But, for us, complexity is not the issue. We believe that Perrow creates a self-fulfilling prophecy. Leaders and workers with the mind-set that accidents are inevitable will—inevitably—have accidents.

[6] The psychology of human error has been studied for over a hundred years (Zimbardo and Gerrig 1996, p. 13). Accidents and safety have been researched from a business perspective for almost that long. Though the term "organizational error" is relatively new (Rasmussen 1990; Reason 1990b), the notion that factors within a complex system can contribute to an accident has been around for a number of years (e.g., Rasmussen, 1981)—and even longer if we consider the AEC's 1928 study.

[7] Perrow asks, "If we have a well designed system, what, then, is left to cause accidents? One obvious possibility is human error (p. 133)." Our rejoinder counters with, "What, then, causes human error?" We will reengage that question and answer it when we talk about culture.

[8] These "aggregated activities" (Farish 1999) may have delayed consequences; hence the term "latent organizational errors" was coined (Grabowski and Roberts 1996; Reason, 1990a and b). These errors might result from inadequate maintenance practices that lead to time-delayed failures.

Latent errors might result from poor designs that later on force operators to improvise solutions (Vincente and Rasmussen 1992). Similarly, catastrophes may result from prior, inadequate risk-management strategies, of the type that led to the Space Shuttle Challenger accident (Baron and Paté-Cornell 1999).

[9] Perrow views an accident as an event in and of itself. However, taking a more holistic view of accidents can create some interesting insights. Consider this definition proposed by the American Engineering Council (AEC) (p. 9, 1928). "A physical accident must be looked at, not as a thing in itself, but as evidence of an inability to harness and control the forces of production. When industrial forces are brought under perfect control there will not only be a maximum of production, but the unexpected, that is, accidents, will not happen; and conversely, when accidents cease to happen it is probable that the cause may be looked for in an industrial organization (system) so well adapted to the problem in hand that the maximum of production is being secured."

[10] Weick (1989) argued that High Reliability Organizations believe "even when human error does occur, the root cause is considered to lie with the organization as a whole rather than being displaced onto the erring task group or individual." This is not a unique view. The nuclear, construction, and transportation industries are dealing with the misconception that the root cause of an accident is always human error and that it is essential to examine the organizational contributing factors (Goglia 1998; Abdelhamid and Everett 2000). Even event-tree, risk analyses are beginning to systematically incorporate organizational factors into estimating the occurrence of errors and accidents (Heslinga and Stassen 1992; Modarres, Mosleh, and Wreathall 1992; Weick 1993; U.S. Forest Service 1994; Stanton 1996).

HROs, including those with world-class safety records, have achieved their status by firmly believing that all levels of an organization can determine how one individual acts. HROs have leveraged that belief by controlling the factors that lead to accidents.

[11] The data in the AEC (1928, p. 30) study convince us that accidents can be controlled—if not directly—at least indirectly by merely controlling the production culture. This conclusion means we do not have to be at the mercy of an opaque, complex system—one that is inherently uncontrollable—as Perrow would have us believe.

[12] Since we have found no other study that questions the methods or disputes the findings of this document, we offer the study's recommendation to today's CEOs. "In every one of these cases (companies showing a relationship of productivity to safety) the result has been not casual and accidental; it has been the result of long-continued, careful effort; it has been obviously the carrying out of an executive policy. The executive had not only an interest, but a vision of safety and a growing belief in the possibility of realizing it, and he went to work to attain it through the peculiarly effective ways that are known to executives." (AEC 1928, p. 7, parentheses added)

[13] Grabowski and Roberts (1996), Roberts (1993), Roberts et al. (1994), and Chiles (2001) have carefully studied these organizations.

[14] What sets HROs apart is that HROs take the systems approach to safety to a level higher than most organizations—and in a fashion similar to those described by the AEC in 1928. In his book *Inviting Disaster* (2001), Chiles concurs with the HRO researchers, writing that "people can safely handle just about any risky business if they organize themselves in a principled fashion. Those few key elements (are): a priority on safety from top to bottom; deep redundancy so the inevitable errors or malfunctions are caught in time; a structure that allows key decisions at all levels; workers who keep their skills sharp with practice and emergency drills; and a premium on learning lessons from trials and errors." (p. 62, parentheses added) To be certain, some of the organizations that have been studied under the rubric of HRO have safety records that fall outside the range of what might commonly be considered "world-class." To their defense, many of the HROs studied, like naval air carriers, are forced to run on the very edge of human performance. But what is common to both HROs and those companies with world-class management systems and safety records is their cultural commitment to control errors through disciplined management (Sullivan and Harper, 1996).

[15] They adapt by using the basic principles of a system architect (Rechtin 1991). That is, HROs learn through carefully constructed and managed error sensing and correcting systems.

[16] Do they have "organizational wisdom"? Do they use band-aids? Or do they use principles? To answer these questions, we turn to what is known about "managerial wisdom." Bigelow (1992, p. 146) believes that "the essence of managerial wisdom lies not simply in a person's knowledge, but in a person's 'meta-awareness' of knowledge and its limitations, and the corresponding ability to deal with ill-defined problems." Meta-awareness makes reference to the principles that underlie a phenomenon.

[17] The inability of managers and workers to understand these risks and interdependencies and interrelationships results in a safety system breaking down (Thomen, 1991; Bennett 1994; Souter 1996). If an organizational architect focuses only on "developing mechanisms by which human error can be corrected and ignores the sources and causes of the errors, the system will never function at an optimal level" (Nieves and Sage 1998).

BIBLIOGRAPHY

Abdelhamid, Tariq S. and Everett, John, G. "Identifying root causes of construction accidents." Journal of Construction Engineering and Management 126 No.1 (January-February 2000): 52-61.

Advisory Committee for Safety in Nuclear Installations. Human factors study group third report: Organising for safety. London: HMSO, 1993.

American Engineering Council, Safety and production. New York: Harper and Brothers, 1928.

Bandura, A. Social learning theory. Englewood Cliffs: Prentice-Hall, 1977.

Bandura, A. Social foundations of thought and action: A social cognitive theory. Englewood Cliffs: Prentice-Hall, 1986.

Baron, Michelle M. and Paté-Cornell, M. Elisabeth. "Designing risk-management strategies for critical engineering systems." IEEE: Transactions on Engineering Management 46 No.1 (February 1999): 87-100.

Bennett, C. Thomas. "The role of risk-based prioritization in total quality management: The integration of quantitative policy analysis and the management of uncertainty." University of California UCRL-ID-119329, 1994.

Bennett, C. Thomas. "Why some laboratories were successful in changing their safety cultures." University of California UCRL-JC-132886, 1999.

Bigelow, John. "Developing managerial wisdom." Journal of Management Inquiry 1 No.2 (June 1992): 143-153.

Chiles, James R. Inviting disaster: Lessons from the edge of technology. An inside look at catastrophes and why they happen. New York: HarperCollins, 2001.

Cooper, M.D. "Towards a model of safety culture." Safety Science 36 (2000) 111-136.

Cox, Sue, Tomas, Jose M., Cheyne, Alistair, and Oliver, Amparo. "Safety culture: The prediction of commitment to safety in the manufacturing industry." British Journal of Management 9 (September, 1998): 3-12.

Dumas, Lloyd J. Lethal arrogance: Human fallibility and dangerous technologies. New York: St. Martin's Press, 1999.

Farish, Mike. "System failure." Engineering, 240 No.9 (October 1999): 38-40.

Geller, E. Scott. "Ten principles for achieving a total safety culture." Professional Safety (September 1994): 18-24.

Goglia, John. "The way things are done around here: Effects of corporate culture on accidents." Mass Transit 24 No.6 (November-December 1998): 22-24.

Grabowski, Martha and Roberts, Karlene H. "Human and organizational error in large scale systems." IEEE: Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans 26 (January 1996): 2-16.

Guastello, Stephen J. Chaos, catastrophe, and human affairs: Applications of nonlinear dynamics to work, organizations, and social evolution. Mahwah: Lawrence Erlbaum Associates, 1995.

Guzzo, R.A. and Dickson, M.W. "Teams in organizations: Recent research on performance and effectiveness." Annual Review of Psychology 47 (1996): 307-338.

Heinrich, H. W. Industrial accident prevention. New York: McGraw-Hill, 1959.

Helmreich, Robert L., Wilhelm, John A., Klinect, James R., and Merritt, Ashleigh C. "Culture, Error, and Crew Resource Management." In Improving Teamwork in Organizations, Eds. Salas, Eduardo, Bowers, Clint A., and Edens, Eleana. Mahwah; Lawrence Erlbaum, 2001.

Heslinga, G. and Stassen, H.G. "The prediction of human performance safety with event trees." IEEE: Transactions on Systems, Man, and Cybernetics 22 No.5 (September-October 1992): 1178-1182.

Hislop, Richard D. Construction site safety: A guide for managing contractors. Boca Raton: CRC Press, 1999.

Hoffman, David A., Jacobs, Rick, Landy, Frank. "High reliability process industries: Individual, micro, and macro organizational influences on safety performance." Journal of Safety Research 26 No.3 (Fall 1995): 131-150. Amsterdam: Elsevier, 1988.

Hoyos, Carl G. and Zimolong, Bernhard. Occupational safety and accident prevention: Behavioral strategies and methods, 1988.

Libuser, Carolyn B. Organization structure and risk mitigation. Ph.D. Dissertation, University of California, Los Angeles, 1994.

Locke, E.A. and Latham, G.P. A theory of goal setting and task performance. Englewood Cliffs: Prentice-Hall, 1990.

Manuele, Fred A. "Perspectives on behavioral safety: Observations of ASSE's behavioral safety symposium." Professional Safety (August 1998): 32-37.

Mearns, Kathryn J. and Flin, Rhona. "Assessing the state of organizational safety—Culture or climate?" Current Psychology 18 No.1 (Spring 1999): 5-14.

Medina, Barbara F. Structured systems analysis: A new technique. New York: Gordon and Breach, 1981.

Modarres, M., Mosleh, A., and Wreathall, J. "A framework for assessing influence of organization on plant safety." Reliability Engineering and System Safety 38 (1992): 157-171.

Nieves, Jose M. and Sage, Andrew P. "Human and organizational error as a basis for process reengineering: With applications to systems integration planning and marketing." IEEE: Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans 28 (November 1998): 742-762.

O'Toole, Michael. "The relationship between employees' perceptions of safety and organizational culture." Journal of Safety Research 33 (2002) 231-243.

Perrow, Charles. Normal accidents: living with high-risk technologies. Princeton: Princeton University Press, 1999.

Popper, Micha and Lipshitz, Raanan. "Organizational learning mechanisms: A structural and cultural approach to organizational learning." Journal of Applied Behavioral Science 34 (June, 1998): 161-180.

Rambo, W.W., Chomiak, A.M., and Price, J.M. "Consistency of performance under stable conditions of work." Journal of Applied Psychology 68 (1983): 78-87.

Rasmussen, J. "Models of mental strategies in process plant diagnosis." In J. Rasmussen and W. Rouse (Eds.), Human detection and diagnosis of system failures. New York: Plenum, 1981.

Rasmussen, J. "The role of error in organizational behavior." Ergonomics 33, No. 10/11 (1990): 1185-1190.

Reason, James T. Human error. Cambridge: Cambridge University Press, 1990a.

Reason, James T. "The contribution of latent human failures to the breakdown of complex systems." Philosophical Transactions of the Royal Society (London) 327 (1990b): 475-484.

Reason, James. Managing the risks of organizational accidents. Brookfield: Ashgate, 1997.

Rechtin, Eberhardt. Systems architecting: Creating and building complex systems. Englewood Cliffs: Prentice-Hall, 1991.

Roberts, Karlene H. New challenges to understanding organizations. New York: Macmillan Publishing Company, 1993.

Roberts, Karlene H., Stout, Suzanne, and Halpern, Jennifer J. "Decision dynamics in two high reliability organizations." Management Science 40 No.5 (May 1994): 614-624.

Rochlin, Gene I. "Safe operation as a social construct." Ergonomics 42 No. 6 (1999): 1549-1560.

Salas, Eduardo, Bowers, Clint A. and Edens, Eleana. Improving teamwork in organizations: Applications of resource management training. Mahwah: Lawrence Erlbaum, 2001.

Stanton, Neville. Human factors in nuclear safety. Bristol: Taylor and Francis, 1996.

Souter, Gavin. "Safety over the long haul." Business Insurance 30 No.18 (April 1996): 37-38.

Sullivan, Gordon R. and Harper, Michael V. Hope is not a method. New York: Time Business, 1996.

Sulzer-Azaroff, Beth, Harris, Todd C., and McCann, Kathleen B. "Beyond training: Organizational performance management techniques." Occupational Medicine 9 No. 2 (April-June 1994), 321-339.

Thomen, James R. Leadership in safety management. New York: Wiley, 1991.

U.S. Forest Service. Report of the south canyon fire accident investigation team. 1994.

Vincente, Kim J. and Rasmussen, J. "Ecological interface design: Theoretical foundations." IEEE: Transactions on Systems, Man, and Cybernetics 22 (July-August 1992): 589-606.

Weick, Karl E. "Organizational culture as a source of high reliability." California Management Review 29 (1987) 112-127.

Weick, Karl E. "Mental models of high reliability systems." Industrial Crisis Quarterly 3 (1989): 127-142.

Weick, Karl E. "The collapse of sense-making in organizations: The Mann-Gulch disaster." Administrative Science Quarterly 38 (1993): 628-652.

Zimbardo, Philip G. and Gerrig, Richard J. Psychology and life. New York: HarperCollins, 1996.

Zohar, Dov. "Modifying supervisory practices to improve subunit safety: A leadership-based intervention model." Journal of Applied Psychology 87 No. 1 (February 2002): 156-164.

BIOGRAPHIES

C. THOMAS BENNETT

After being commissioned in the U.S. Army, Tom earned his Ph.D. in psychology in the field of neuroscience. During his military career, he conducted research in the behavioral and neuropharmacological effects of nerve agents, the management of radiation sickness, and effects of lasers on pilot performance. His research involved both laboratory studies of various weapon systems and field study of various stressors on special operations unit performance, particularly in aviation. He retired as a senior research psychologist from the Army in 1991. At the University of California, Tom developed the use of Crew Resource Management to control human error during nuclear weapons dismantlement and the laser enrichment of uranium. He is currently a human factors engineer working with various NIF line managers to better understand human error during the assembly and commissioning of the laser. Tom is a member of the Human Factors Society.

GEORGE F. STALNAKER

As a DuPont construction safety consultant, George worked for DuPont Petrozuata Vehop as a safety manager on the joint Conoco/Venezuela Heavy Oil Project. The project was a $2B refinery effort that involved a peak workforce of 6,000. The project's recordable rate over 18 million worker hours was 0.69. Working as a safety manager on several DuPont construction projects in Asia and the Pacific, the companies he supported achieved a recordable rate of 0.48 spanning 34 million worker hours. George also worked as the safety superintendent at DOE Savannah River Plant. He is the recipient of a number of safety awards including the prestigious Conoco President's Award for 1999, DuPont's Gold Plumb, Silver Triangle, Best TRR Performance, Engineering Safety Excellence, and others. At the University of California, he helped NIF develop its basic safety practices. George is a member of the American Society of Safety Engineers.